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## Monitoring and Modeling of Urmia Lake Area Variations Using Artificial Neural Network


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### Abstract

Urmia Lake is one of the largest hypersaline lakes in the world and the largest inland body of salt water in northwest of Iran, which has been in a critical situation over the last few years. In this paper, Urmia lake and its basin variations were monitored, then the ability of artificial neural network for predicting the lake's area was evaluated. For observing environmental variations, monthly precipitation was computed using TRMM satellite dataset. Terrestrial Water Storage (TWS) and TWS Anomaly (TWSA) were estimated from GLDAS hydrological dataset and GRACE mission respectively. To monitor lake itself Jason-1, Jason-2/OSTM, Jason-3, and MODIS satellite altimetry and MODIS data were used to compute lake's Water Level (WL) and area. These five parameters were estimated over 183 months from April 2002 to June 2017. Moreover, variation of the lake during that period was modeled, using two ANN methods of MLP and LSTM. The LSTM model reached RMSE (for normalized data) of 0.0511 which demonstrates its reliability. To predict Urmia lake's further changes, 4 model were constructed to predict lake area in next 3, 6, 9, and 12 months. Hence, the LSTM network modeled next 3 and 6 month with a suitable RMSE (0.0882) and also with an appropriate ability to predict area fluctuation caused by seasonal changes.


**Keywords:** ANN, Neural network, Prediction, Urmia Lake, Water level

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**Expanded Abstract**

**Introduction**

Due to increase of water exploitation and drought, the need for water resources has been risen in past decades. Numerous regions around the world are under threat of environmental crisis, as a result of climate change. Declination in the amount of precipitation can be led to various subsequences, such as significant reduction in the level of ground and surface water, e.g., lakes. Through the development of satellite imagery systems, it is possible to monitor and evaluate changes in rainfall, groundwater level, surface water area, and level.

Urmia Lake is one of the largest hypersaline lakes in the world and the largest inland body of salt water in northwest of Iran. The lake and its corresponding basin were in a catastrophic situation and under threat of drying up. The lake's area and WL were decreasing from 1995 due to climatic change and anthropogenic activities. Irrigation expansion after 2000 was indicated as the dominant human driver of the Lake Urmia desiccation.

Remote sensing provides certain tools for monitoring lakes and their basin over time and space. Numerous studies have been conducted to observe and evaluate climate change after the launch of Gravity Recovery and Climate Experiment (GRACE) satellite mission. GRACE dataset has been used widely to determine water storage variations over the world as well as Iran. This satellite data has been used for various purposes including ground and surface water monitoring. Employing this dataset beside precipitation and satellite altimetry data have been used for observing changes in watersheds and lakes in numerous studies. Modelling and predicting environmental and climate changes are always an important task. Gathering several remote sensing data and predicting them would be helpful mostly for disaster management and also decision making.

Therefore, it is possible to observe and evaluate variation in rainfall, groundwater level, surface water area, and level. In this study, Urmia Lake and its watershed changes were monitored using various satellite data such as TRMM, GLDAS, GRACE, MODIS. Moreover, machine-learning based methods were developed to predict the lake surface changes.

**Materials and Methods**

To monitor Urmia Lake changes, several data were used to survey variation in precipitation, ground and surface water storage, lake water level, and area in 183 months from April 2002 to June 2017. Sufficient temporal resolution of the data is an essential factor in monitoring of changes through the time. Accordingly, for monitoring the overall change of the Urmia lake, we prefer a satellite data with at least monthly temporal resolution. Therefore, overall variations of the lake and its corresponding basin were modeled using these data with adequate temporal resolution.

Tropical Rainfall Measuring Mission (TRMM) is an international collaboration which aims to observe rainfall for environmental studies. TRMM data provides precipitation in various temporal and spatial resolutions. In this study, TRMM-3b43 level 3 monthly data, with 0.25 degree spatial resolution estimates rainfall in Urmia lake basin, including 83 pixels in each time step.

The GLDAS hydrological model consists of various variables (e.g., soil temperature, soil moisture, precipitation, etc.). In this study, the GLDAS data with 1 degree spatial resolution provides terrestrial water storage (TWS) by integrating soil moisture (kg $m^{-2}$), snow water equivalent (kg $m^{-2}$), and canopy water storage (kg $m^{-2}$). Three types of monthly GLDAS model data (MOS, VIC, and NOAH) were hired for this purpose.

GRACE is a joint mission between Germany and the USA, giving information about mass changes within Earth. The level 2 (RL05) data was of GRACE used to monitor TWSA, which was computed from spherical harmonics using methods developed by Wahr and Swanson. In addition, a 300 km Gaussian filter was applied to reduce high frequency noises.

The investigated Global Reservoirs and Lakes Monitor (G-REALM) dataset including Jason-1, Jason-2/OSTM, and Jason-3 altimeters were employed to survey Water Level (WL) variation of Urmia lake.

In order to monitor lake extent changes during the 17 years, MODIS atmospheric corrected product MOD09Q1 version 6 data, with 250 m spatial and 8-day temporal resolution was used through Google Earth Engine. The product provides surface spectral reflectance of bands 1 and 2, which is the composite of 8 products with the absence of clouds, cloud shadow, and aerosol loading. Although, the Normalized Difference Water Index (NDWI) is a common method to separate water from land and it also had the best result on Landsat data, Normalized Difference Vegetation Index (NDVI) performs transcendent distinguishing between water and land while using MODIS data and also in the specific case of Urmia Lake. Therefore, in this study, the NDVI index was chosen as an appropriate index to separate water and non-water. To determine lake area, first, water region was detected. Then, area of water extent was computed as lake area.

For modeling the lake's area variation, machine learning based methods were investigated. As a time-series prediction problem, a Multilayer Perceptron (MLP) and a Long Short-Term Memory (LSTM) networks were constructed using TRMM rainfall, GLDAS, GRACE TWS, and altimeter WL as inputs (predictors) of the models, and lake's area as Target. About 80% of data was assigned to training, 10% to validation, and the same portion to test. A feedforward MLP including one hidden layer and 5 neurons and a Recurrent LSTM network with same hidden layer and 10 neurons, were obtained. In order to evaluate network's performance, Root Mean Square Error (RMSE) was used. In addition, the delay parameter of 12 months or one year was chosen for estimating future variations.

**Discussion of Results**

Except seasonal changes, amount of monthly rainfall during the mentioned period experienced a significant decrease from 2004 to 2008, and then it fluctuates to 2017. The changes in precipitation rate can affect other parameters considerably. As a result, water mass variation obtained from GLDAS data, falls from 2003 to 2008, and after that, similarly to rainfall variation, it fluctuates. However, TWSA computed by GRACE data, after reduction to 2008 and rise to 2010, behaved otherwise, and it went down steadily to 2017. Urmia Lake WL declined during the whole period. This decrement was intensified from 2006 to 2010, after that it halted gradually to 2017 as consequence of increase in rainfall rate. Area of the lake decreased from 2004 to 2015, also it faced an extreme fall in 2008. Next, to 2017, the area increased slightly.

Due to a decade drought of Urmia Lake, it was in critical circumstance. Consequently, estimating future variation of the lake is necessary. Instead of using physical models or assessing the impact of each parameter on the surface of the lake directly and indirectly, which are complicated tasks, a machine-learning based method is hired. Disregarding the exact relation between factors, this learning-based method can determine and model changes. By using two of the most common ANN based methods including MLP and LSTM, variation of the lake during that period was modeled.

MLP and LSTM models reached overall RMSE (for normalized data) of 0.0586 and 0.0511, respectively, which indicates reliability of both models for predicting lake area changes; however, LSTM network performed superior specially over test data (RMSE of 0.0487). In addition, to predict Urmia Lake's further changes and assess LSTM model capabilities comprehensively, four networks were constructed to predict lake area of next 3, 6, 9, and 12 months. Accordingly, result demonstrates LSTM abilities for predicting upcoming year variation of the lake with RMSE of 0.0882 (better than prediction for 6 and 9 months).

**Conclusions**

Variation in each part of environment and climate (such as rainfall, TWS, WL and area of lakes) affects others. Therefore, it is possible to monitor and model these relations between the parameters. In this study, two ANN methods of MLP and LSTM were investigated to model Urmia Lake surface area which the LSTM model performed transcendent. Moreover, LSTM method provides a model which is able to predict the lake area of next 12 months with a high accuracy.

In order to improve the network's accuracy, it is suggested to increase the number of data and parameters, which are used as network input. It would help the network to implement the training stage with a higher capability to recognize diverse situations properly.